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OF

THE ENGINEERING SOCIETY

OF

THE LEHIGH UNIVERSITY.

ISSUED QUARTERLY.

FEBRUARY, 1888.

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ABSTRACT OF PROCEEDINGS.

Thursday, January 19, 1888.—President Davis in the chair and eighteen members present. Committee on room reported that they had ordered a book-case, two locks and keys to the same, at a cost of $18.90. The following Juniors were elected to membership: Messrs. Wm. Butterworth, P. Atkinson, L. Henderson, R. H. E. Porter, C. P. Turner, E. A. Wright, H. M. Carson, W. A. Cornelius, J. M. S. Kerlin, A. L. Rogers, H. R. Woodall, C. W. Corbin, G. W. Harris, J. T. Morrow, C. W. Schwartz, J. B. Wright.

On motion it was decided to meet at 4 P. M., Tuesdays, until otherwise ordered. On motion of Mr. Villalon, the Society extended its thanks to Prof. Merriman for supplying a long felt want by his new book on Roofs and Bridges. The papers read at this sitting were, "Moving the Conestoga Bridge," by C. H. Miller; "Development and Practice of Forestry in Europe," by C. E. Raynor, and "Easement Curves" by S. W. Frescoln.

Tuesday, January 31.—The President in the chair and forty-two members present. Prof. Merriman addressed the Society on its present and future prospects, offering many valuable suggestions. A paper on "The Thrust of Earth Behind Retaining Walls" was read by Mr. Spalding. Mr. Zollinger read a paper on the "Construction of a Spiral, or Skew Arch," written for the Society by

M. P. Paret, '78, Division Engineer C. & R. R. R., Oakley, O. After some discussion it was decided to adopt the 24-hour system of reckoning time for all notices of the Society.

A committee, consisting of Messrs. Parker, McClintic and Stevenson, was appointed to revise the Constitution and By-Laws.

C. J. PARKER, Secretary.

THE CONSTRUCTION OF A SKEW OR SPIRAL ARCH.

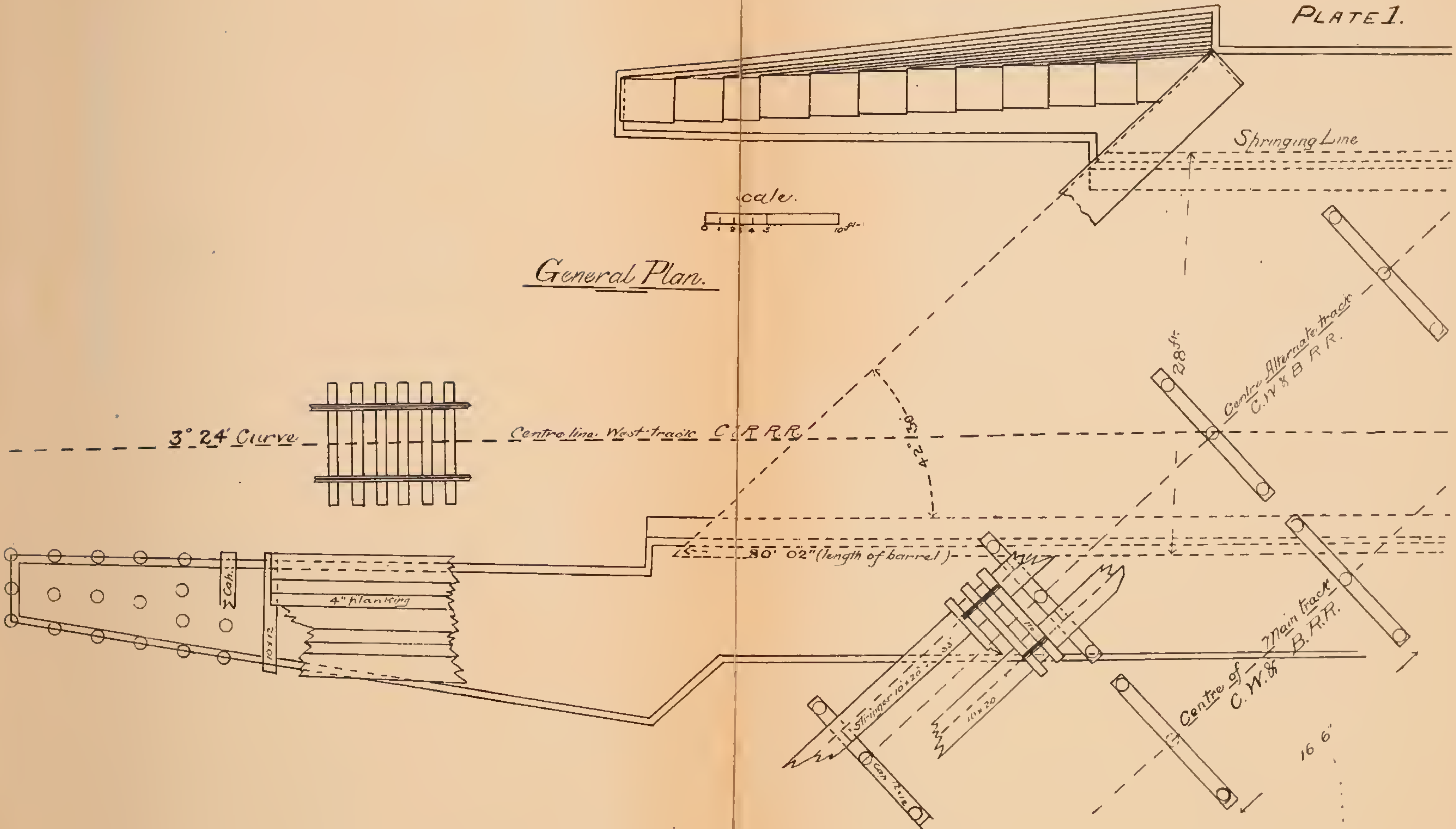
WRITTEN BY M. P. PARET, '78, DIV. ENG. C. & R. R. R.

As a preface to this paper, it might be well to say that it has been made a sort of history of interesting points in the construction, trusting that it would be found more interesting than if the same space had been given to detail in the matter of developments, spirals, etc., no more of which has been introduced than is necessary for proper illustration and conception.

The Cincinnati & Richmond Railroad is being built by the management of the Pennsylvania Lines west of Pittsburgh, with a view of further developing and relieving existing lines. It connects with the Little Miami Railroad at Red Bank Station, about seven miles from Cincinnati, and runs northwest through Reading and Hamilton, Ohio, to Richmond, Indiana. Only the portion between Red Bank and Hamilton is now under contract. About two miles from Red Bank it crosses the Cincinnati, Washington & Baltimore Railroad, under grade; at which point was built the spiral arch, the subject of this paper.

The C. & R. is in fill here (about eight feet,) and top of rail is about twenty-seven feet below that of the C., W. & B.; this makes the C., W. & B. embankment about thirty-five feet high. The alignment of the C., W. & B. is straight, with an ascending grade each way from the crossing of about $1\frac{5}{10}$ per cent. The grade on the C. & R. is 0.4 per cent. ascending, and the alignment a 3° 24′ curve to the left, a tangent to which makes an angle of 42° 30′ to the left with the C., W. & B. at the intersection. About one hundred feet to the right of the crossing is a twenty foot full centered arch under the C., W. & B., through which runs a stream called Duck Creek. This is a very rapidly rising and turbulent stream in high water, changing its channel and overflowing the adjoining flats to a depth of four or five feet; in such cases the twenty foot arch would run nearly crown full.

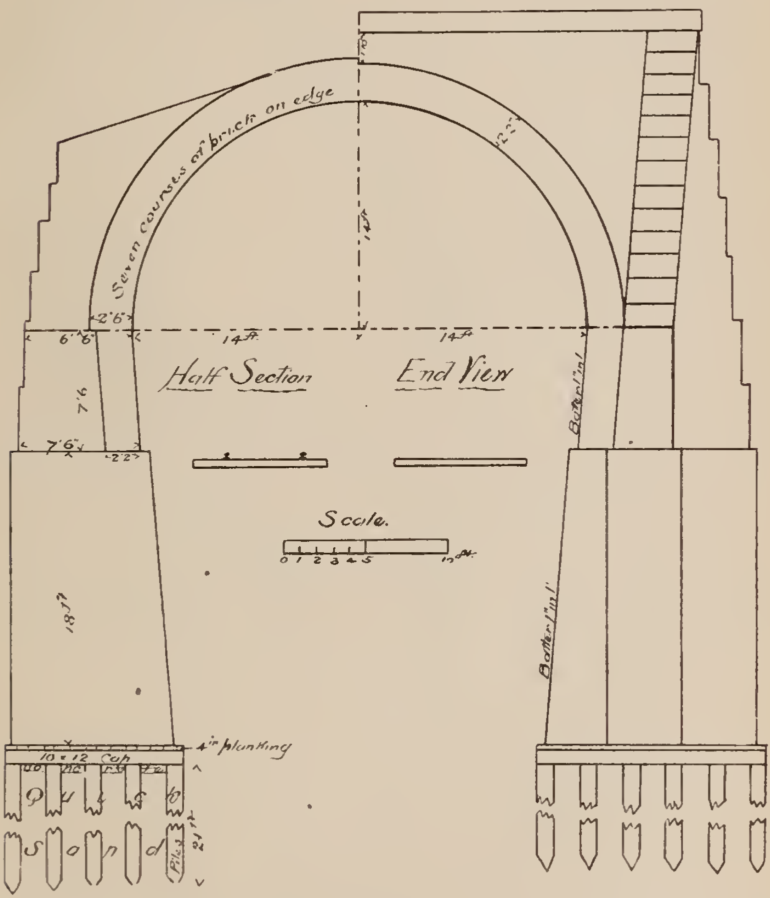
PLATE 1.



Springing Line
General Plan.
3° 24' Curve
80' 02" (length of barrel)
4" planking
Centre Alternate track C.W. & B. R.R.
Centre of Main track C.W. & B. R.R.
Stringer 10×20
10×20
10×12
16' 6"
28 ft.
42° 30'

Test pits were sunk near the crossing to the water level in the creek, and then borings taken in these to a depth of about twelve feet below water level; the result was, loam and earth to a depth of six feet, two or three feet of blue clay, two feet of coarse sand,

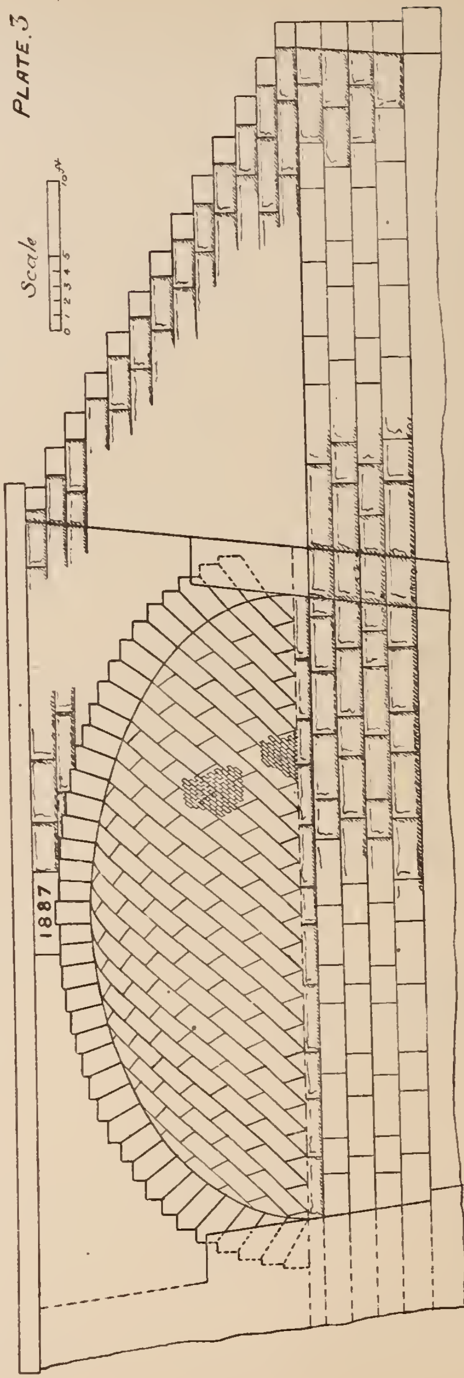
PLATE 2



then fine quicksand to bottom of boring. In view of the unstable character of the foundation, and importance of the structure, it was decided to have a pile foundation. It might be mentioned in this connection that two bridges over Duck Creek, one directly above and the other below the skew arch, have pile foundations. In digging the test pits, we found five feet below ground surface, some flooring timbers of an old shanty which was used at the

time of building the C., W. & B., in the year 1865; this is interesting as showing the amount of sediment deposited by overflows of the creek in a period of twenty-two years. The C., W. & B. embankment was cut through to a level with the original ground surface, and then the foundation pits proper to a depth making the top of timber below low water level of the creek; this made the excavation forty-five feet below the level of the C., W. & B. The method used to carry the traffic overhead without interruption was that of the alternate use of two pile trestles. To this end piles were driven for the main line trestle with a track pile driver. There were three piles to the bent, one in centre of track and one at 5.5 feet each side; the bents were 16½ feet *c* to *c*, and in all thirteen bents. The leads would not take longer than 30 feet piles. The alternate trestle was

PLATE 3



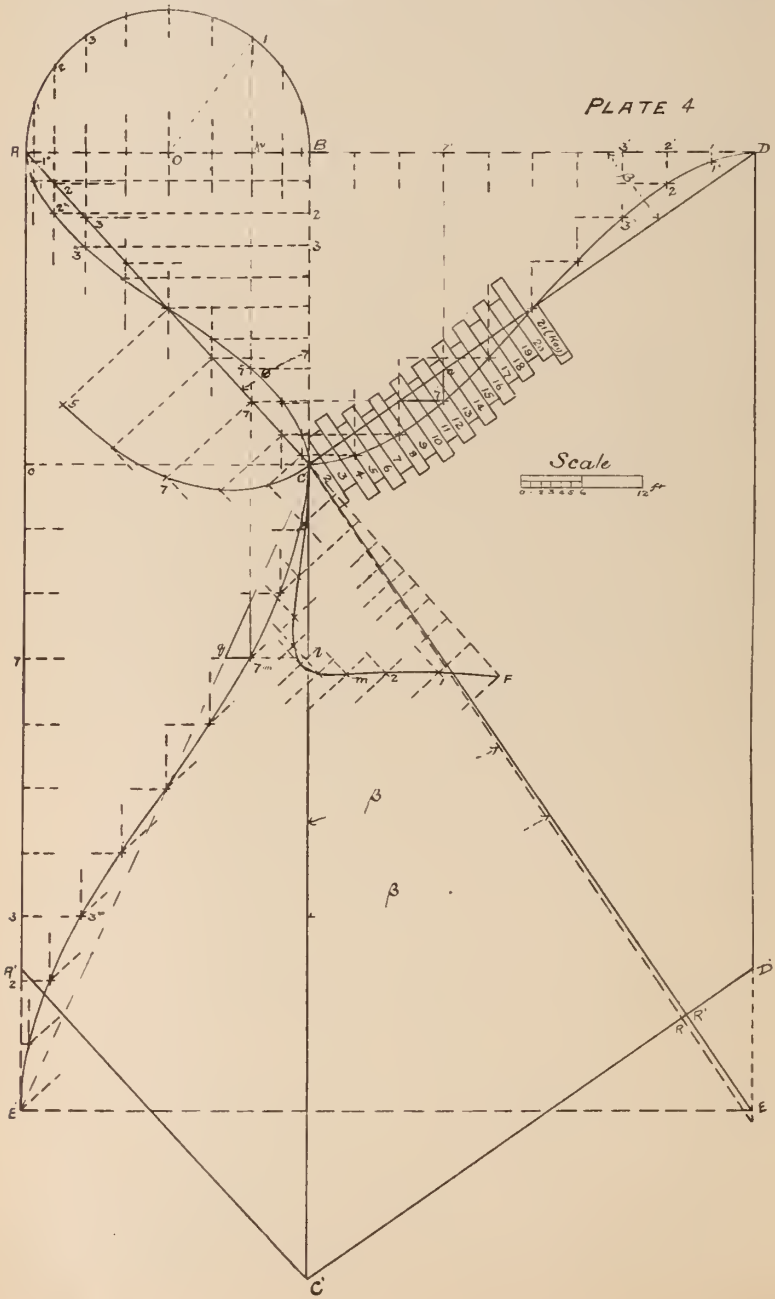
FACE ELEVATION

fourteen feet from the main one *c* to *c*. The piles were driven with a land driver, and the location coming somewhat down the slope of the fill we were enabled to use 45 feet piles. In case the location of the pile came within the limits of the masonry the pile was not driven, but square timber substituted in the later construction. The caps were framed on the bents, the stringers slipped under the track, hewn ties replaced by bridge ties, guard rail, etc., without delaying travel. The stringers used were 10″x20″, doubled under each rail, and expected to carry the double span in case of emergency. The trestles were thoroughly braced as the excavation proceeded; the bents of the alternate trestle were of great service to the main trestle in making the sway bracing effective. When a depth of twenty-seven feet below the track was reached the material directly under the main track was left standing, and that included between the rest of the abutments and the wings, was taken down to the natural ground level. A row of piles about eight feet apart was then driven all around and just clear of the foundation. The pits proper were then excavated to the required depth, sheeting being spiked to the piles, and the work proceeded. Twenty and twenty-five feet piles were first used, but later the length was increased to obviate the use of a follower which did not give satisfaction. The weight of the hammer used was 2,780 pounds, and with a fall of 25 feet the average penetration under the last blow was 1 ½ inches. The piles were then sawed off to a level bearing, and 10x12 caps bolted to them, running across the wing or abutment, the drift bolts used being of 1 inch square iron 16 inches long. The intervening space was filled with well rammed concrete to a depth of 8 inches below the bottom of cap and until it flushed level with the top of the same. Four inch planking was then spiked to the caps lengthwise with the abutment. Several heavy storms and overflows of the creek caused considerable damage and delay in the way of filling up the pits and starting slides. Having built up the masonry to the springing line, and as close to the main trestle as safety would allow, travel was thrown over the alternate and the main trestle torn out. The pits were excavated for the rest of the abutments, and the masonry finished throughout to the springing line.

Plate No. 1 shows a general plan and location; Plate No. 2, a half section and end elevation; Plate No. 3, elevation of face and wing.

We now come to the development of the arch, by which is

obtained the dimensions of the impost, quoin and ring stones. The arch is full centered with a span of 28 feet at the springing line, the length on the skew, 80 feet and 2 inches, is apparently



extreme, but by agreement with the C., W. & B. R. R. Company, it was built to allow for a proposed raise in their present grade of eleven feet.

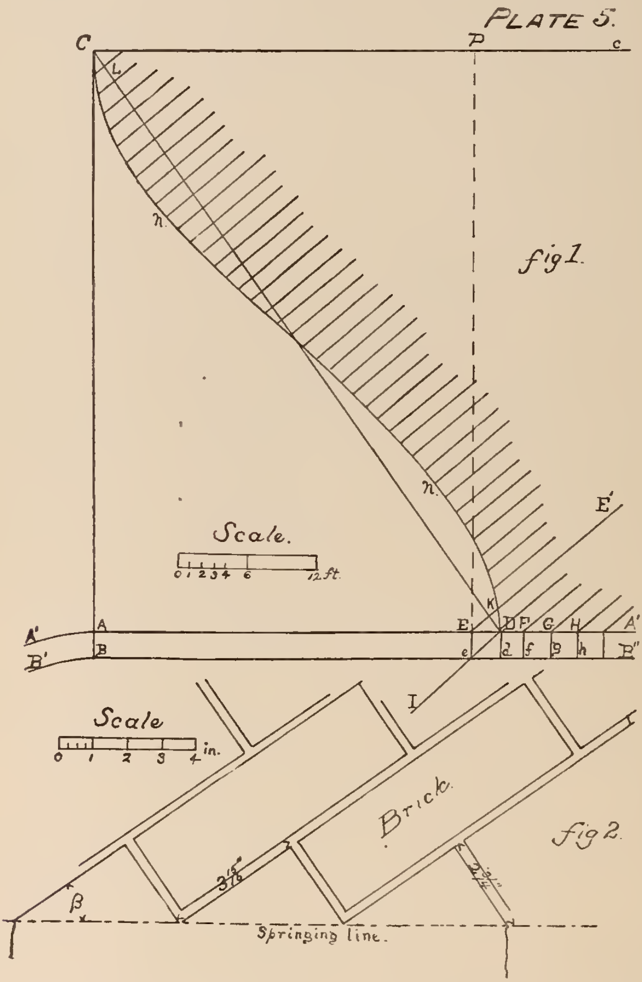
Plate No. 4 shows the development of the arch and obtaining of the coursing and heading spirals. Referring to this plate $A\,C\,C'\,A'$ is plan of arch at springing line, $A\,A' = 80'\,2''$ $A\,C = 41.44'$ the skew span. $A\,B = 28'$. $O\,A$, the radius, $= 14'$, $A\,C\,B =$ the angle of obliquity $= \theta = 42°\,30'$.

To obtain a heading spiral, with $C\,C'$ as an axis, develope the intrados or soffit. A will fall at D, A' at D', $B\,D$ being equal to $43.98'$ or the semi-circumference of a circle of $14'$ radius. By calculation $B\,C = 30.55'$, then in triangle $B\,C\,D$ by calculation the angle at $D = \beta = 34°\,47'\,22''$; this is called the angle of the intrados and is the angle made by the intersection of a coursing spiral with the axis of the arch, in development.

Join $C\,D$, draw $C\,E$ perpendicular to it, $C\,E$ is then the direction of an intradosal coursing joint, and the angle $E\,C\,C' = \beta$. With O as a centre, describe the semi-circle on $A\,B$, divide this into a number of equal parts 1, 2, 3, also divide $B\,C$ into the same number of equal parts; the corresponding points projected to an intersection will form the heading spiral $A\,3'''\,7'''\,C$. By laying off the distance $B\,C$ along the springing line $C\,C'$, a heading spiral can be obtained at any desired point. Now if the development be rolled back again, E will fall at E', which will be the other extremity of the coursing spiral through C. Project C across to c, divide $c\,E'$ into the same number of equal parts as was the semi-circle, project corresponding points to an intersection, and we have the coursing spiral $C\,7''''\,3''''\,E'$. To obtain a mould with which to draw the coursing joints as shown on Plate No. 3, extend the line E' $1''''$, $2''''$, $3''''$, etc., let fall perpendiculars, and on these lay off from $C\,F$ the corresponding sines measured from $A\,B$ to 1, 2, 3, etc. Joining the points so found gives the curve desired $F\,1\,m\,C$. In a similar manner is found the curve $C\,7\,r\,5$, which gives a mould with which to draw the heading spirals on Plate No. 3.

The face of the arch being made by a vertical plane passed through the ends of the springing line, the face end of the ring stones will not follow a heading spiral on the soffit. This vertical plane cuts the soffit in an ellipse shown by the straight line $A\,C$, or in development by the spiral $C\,7''\,3''\,D$. If we divide $C\,D$ into an odd number of equal parts, we obtain the number and thick-

ness of the ring stones. (Divide $C' D'$ similarly, then if CE does not intersect $C'D'$ at one of these points of division, it must be made to do so, and an adjustment made in the intradosal angle. In this arch the nearest point of division is $5\frac{9}{16}$ inches from R to-



ward C' and the adjusted angle $\beta' = 34° \; 23' \; 06''$. As the arch was turned with brick, and a coursing spiral could not have been farther away than ½ a course of brick, the adjusted angle was not used. It would be necessary to use it, however, in an arch all stone.) Through these points of division draw lines parallel to CE, lay off the greatest length desired for the longer side of the short stones on CE, through this point draw a spiral parallel to

$C\,7''\,3''\,D$, this will give in plan the length of the short stones, square off the back ends and make the longer stones the desired length; in this case $4\frac{1}{2}'$. $CD = 53.54'$; this divided by 39 gave us $16\frac{7}{16}''$ as the width of each of the 39 ring stones, and conforming with the thickness of six courses of brick on edge. Facing the arch the acute quoin stone on the left is numbered 1, the first ring stone 2, and so on over the arch to the right, the key being 21. The quoin stones 1 and 41 form the skew-backs, from which spring the adjacent ring stones. Ring stone 40 and the quoin stone 41 were made in one stone. A pattern house was built 28'x20' inside, the floor being tongue and grooved and planed. On this was laid off to full size the development of the semi-ellipse or one-half the spiral $C\,7''\,3''\,D$, Plate 4; this was done by means of ordinates found thus: draw 07, connect 7 and $7°$, cutting $A\,B$ at p, then $Op = 07 \cos p07$. $07 = R = 14'$, $p07 = \frac{3}{5}(90°) = 54°$, then $Ap \cot \theta = p\,7° = 7'\,7''$. But $7'\,n = 7'\,D$ tang β. $7'\,7'' - 7'\,n = n\,7''$, the ordinate sought, which is laid off on a line making an angle with $C\,D$ which is the compliment of β. The distance to the foot of this ordinate $= Cn = \dfrac{B\,7'}{\cos \beta.}$

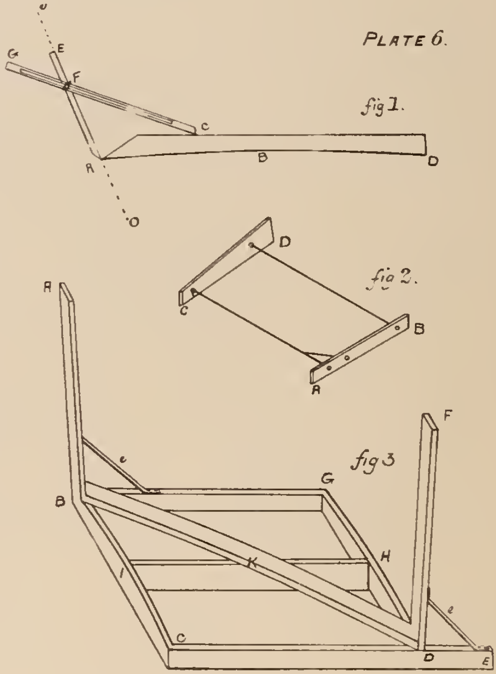
As before described the width and length of the ring stones were laid off and patterns so obtained are for the soffit.

Next, to obtain the face patterns, full sized semi-ellipses or a section of the arch parallel to the face, showing intrados and extrados were laid out on the floor.

The ordinates of the ellipses are readily calculated from the relation the axes bear to each other. To fix the position of the face joints, the full-sized soffit patterns were applied to the intradosal ellipse in proper succession; see Plate No. 7, Fig. 1. $A\,m\,n\,D$; the sum of the width of these patterns, measured along the curved ends, must equal the circumference of the ellipse as the spiral $C\,7''\,3''\,D$ (Plate No. 4) from which they are obtained; this is but the development of the ellipse as before shown. The joints as they appear on the face are not straight lines, but nearly so and may be so taken. These joints do not radiate from the centre of the semi-circle, but from a point O directly below, see Plate No. 7, Fig. 1. This point O is called the centre of eccentricity, and is obtained by calculation, or more easily geometrically as follows: see Plate No. 7, Fig. 2. Make $A\,B = 16'\,2''$, draw $A\,C$ perpendicular to it, making the angle $A\,C\,B = \theta$ and draw $C\,D$ perpendicular to $A\,C$, making the angle $C\,A\,D = \beta$; then in Plate No. 7,

Fig. 1, extend *E C* to *O*, making *C O* = *C D*, Fig. 2. *O* is then the centre of eccentricity, in this case equal to 12.27′. From *O* draw lines through the division *A m n*, etc., and the joints are obtained, from the ends of which at the extrados draw plumb and level lines, and the face patterns are finished. The point of eccentricity fell outside of our pattern house, but a narrow door built the full length of the house, when raised, enabled us to stretch a line from *O* to any point on the face.

To obtain the bed patterns or practically the angle which the face joint makes with a line joining the ends of the stone on the intrados, (which angle varies according to the length of the stone, see Plate No. 7, Fig. 7, and with the heighth of the joint above the springing line,) there are several methods given by the authorities; by calculation, by means of diagrams, by construction from the full-sized face development, etc.



The method used in the construction of this arch was, so far as we know, original with it. A shifting stock was made, see Plate No. 6, Fig. 1, all the pieces of half-inch hard wood. *A D* 7′ long, and 3″ to 4″ wide, *A E* 3′ long, 1½″ wide, *A B D* is cut to a curve to fit the soffit arris or the curve made by the intersection of the warped surface of the bed with the warped surface of the soffit. The obtaining of this curve will be explained later. The arm *A E* is hinged to *A B* at *A*, the point of the hinge being both on the curve *A B D* and staight line *O E*, *C G* is hinged to *A B* at *C* and has a long slot in it, through which passes a clamp *F*, which is countersunk into *A E* to allow the stock to be laid flat on the stone. The clamp screw can be taken out and the arm *C G* put either side of *A E*.

It is evident $A\,E$ can be clamped anywhere within the limits of the slot, which was made long enough to cover the scope of the angles required. As soon as the lagging was all placed on the ribs, the face line was marked over it with the transit from reference points and the soffit patterns laid side by side over the lagging, the points where the joints came along the face being marked and referenced by cross lines; augur holes were bored through the lagging in the approximate direction the joint would take. The excavation was deep enough to drive a nail in a stout stake at the centre of eccentricity; a cord made fast to the nail and passed up through the augur holes and the intersection of the reference lines gave the true direction of the face joints. The shifting stock was set on the lagging $A\,B$ along the coursing spiral, and $A\,E$ clamped in position to just coincide with the line of the cord $O\,e$ as shown. As soon as it was clamped the angle was transferred to paper and a record kept. In using the shifting stock the factor of length of stone did not appear.

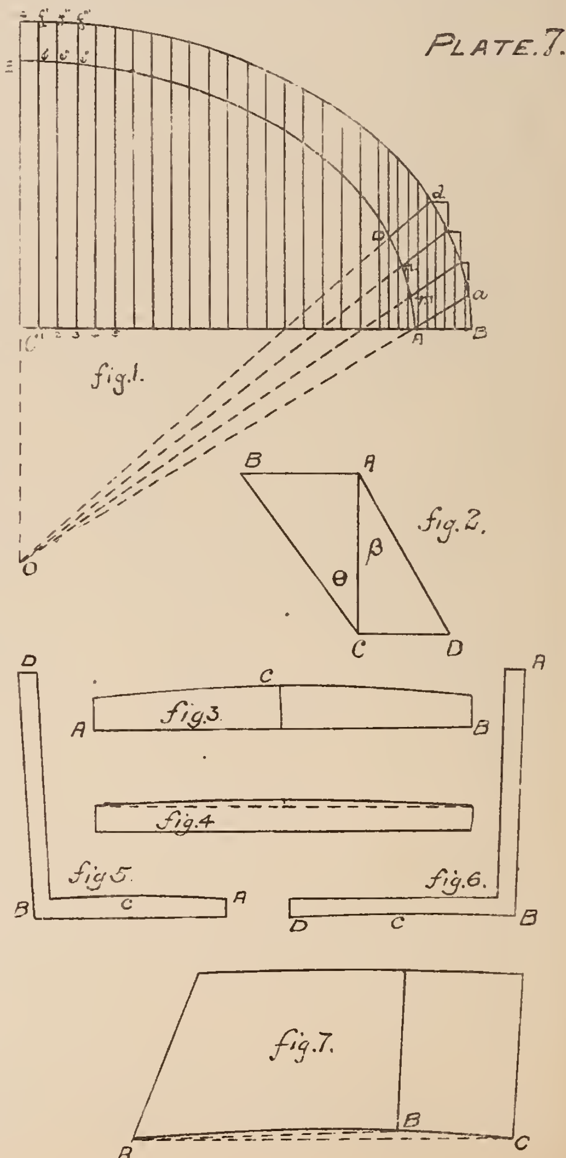
In cutting the ring stone the following moulds and rules were used in addition to the patterns already described. A pair of twisting rules made thus: of half-inch hard wood one rule $2'\ 2''$ long and $3''$ wide, another $2'\ 2''$ long, $3''$ wide at one end, and $5\frac{5}{8}''$ at the other; these were framed together with round steel rods, so that the equal ends should be $3'$ apart and the unequal ends $3'\ 1\frac{13}{16}''$ apart, see Plate No. 5, Fig. 5. There should be play enough in the fastenings to allow the rules to move up and down until either their top or bottom are in the same plane or out of wind. The distance apart $3'$ of the equal ends is an arbitrary distance, the distance at the back $3'\ 1\frac{18}{16}''$ is obtained thus: by calculation the angle of the extrados $A''\,E\,E' = \phi = 38^\circ\ 45'\ 30''$, see Plate No. 5, Fig. 1.

$$(3)\ \frac{\sec\varphi\cos(\varphi - \beta)}{\sec\beta} = 3'\ 1\tfrac{13}{16}''.$$

The extra width $2\frac{5}{8}''$ of the second twisting rule $= (3'\ 1\frac{13}{16}'')$ $\tan\phi = \beta$. Facing the arch the acute angle is to the left and the spiral runs over the arch from left to right, in other words the winding bed of the stone raises behind, or the rule which is $5\frac{5}{8}''$ at the extrados must be on the left when you stand facing the soffit of the stone.

The twisting rules are used to cut the first bed, thus: lay them on the stone with equal ends facing the soffit, run a level draft along the length of the bed at the soffit and another at right

angles to it, in which set the straight edge $A B$ sink a corresponding draft under $C D$ until the tops of the rule are out of wind, take off the twisting rules and cut the rest of the bed until a straight edge laid parallel to the soffit fits the two drafts already cut for the full depth of the stone. Next of ¾″ stuff cut a template, see Plate No. 7, Fig. 4, about 6 inches wide and 6 feet long, with lower edge straight and upper edge to a curve found thus: multiply 6′ by $sin\ \beta$, take the result as a chord of a curve of 14′ radius, calculate the middle ordinate, lay this off as the middle ordinate to the 6′ curve; to get intermediate points multiply (½) 6′ $sin\ \beta$, etc. This gives the same curve as $A B D$, see Plate No. 6, Fig. 1. Lay this template on the bed of stone already cut, close to the soffit as possible for the length of stone required, run a draft or arris along the soffit to the line so obtained; this completes the bed, and from it the soffit is cut by means of a mould, see Plate No. 6, Fig. 3, made thus: use ¾″ well seasoned hard wood, make two templates, see Plate



No. 7, Fig. 5, the arm DB 2′ 2″ long, and each edge on the radius extended, BA has the lower edge straight and the upper cut to a curve of 14′ radius, the curved portion being 1′ 8″ long.

These templates are framed together as shown on Plate No. 6, Fig. 3, CE, IH and BG have all their edges straight, CE being 3′ 6″ long, BG and IH 2′ 4¾″ long, CE and BG 2″ wide, and IH 2⅜″ wide. The length of $BG = HI = CD$ is obtained by using $BC = 1' \, 10''$ and making the angle $BDC = \beta$. The piece BD is 2″ wide bent down over IH and fitting neat with the radial edges of AB and DF. CK, or the perpendicular distance from C to $BD = 16\frac{1}{2}''$ = thickness of a ring stone (includes joint;) $e\,e$ are iron knee braces to stiffen the frame. It is impor- that this mould should be framed together in the most substantial manner and also accurately. Next cut two templates, see Plate No. 7, Fig. 3, ¾″ thick, 6′ long, the bottom straight and top to a curve with radius of 14′, scribe a line on each side at the centre and perpendicular to the bottom, apply the mould, see Plate No. 6, Fig. 3 to the bed already cut with the arms AB and DF on that bed, and the portion BCD against the soffit, sink drafts in the soffit until BC, IK and CD coincide with them; in the draft cut to BC, place one of the templates, Fig. 3, so that its centre is on the draft line CD, place the other similar templates parallel to the first at a convenient distance from it and its centre also on the draft line CD, sink a draft for this till it just touches the soffit arris and is out of wind with the first template. Remove the templates and cut the rest of the bed until a straight edge applied parallel to CD fits the two drafts and the bed throughout. The other bed is either cut by reversing the mould or by gauging the thickness of the stone; the stone cutters will prefer to gauge the stone. This thickness of the stone at the extrados is obtained thus: see Plate No. 5, Fig. 1, in which BB'' is the springing line produced at the intrados AA'' the same for the extrados, DC is the development of an extradosal heading spiral, and $Dn\,n\,C$ is the development of the extradosal ellipse in the face DI; EE' is the development of the extradosal coursing spiral and is in the same spiral surface with the intradosal spiral CE' (see Plate No. 4;) EE' intersects DC at K; to determine the distance DK in the triangle ADC we have known AC and AD from which we obtain the angle ADC, the distance $DE = Ee \cot \theta$. Cc and EE' intersect at some point R, (not shown.) and in the triangle EPR we know EP and PR, and finding the

angle $E' E P$ or its compliment $D E K$, solve the triangle $D K E$ for $D K$; lay off $C L = A D$, divide $K L$ into the same number of equal parts into which $C D$ (see Plate No. 4) was divided, one of these parts equals the thickness of the ring stone at the extrados equals $18\frac{1}{8}''$.

Now the two beds and soffit being cut, set the shifting stock to the required angles and apply to the beds, pitch off the face and run drafts to suit; the face patterns were not applied directly as the face of the stone was left rough, but dimensions were scaled from the floor and direct measurements applied. That the creepers over the ring stone in the face may have a level bed, the ring stone must be squared back from the face drafts. Care must be taken in the acute stones to give the creeper as much bearing as possible without weakening the ring stones. The ring stones were set with Louis-bolts to avoid putting dog holes in the face, the holes being drilled so that the stone would hang in the air as near as possible as it would set on the lagging. The beds of the stones on the acute side having such a sharp pitch it was possible that, while the mortar was green, owing to the jar or tremor of trains passing overhead the stones might slip down a little out of place. To avoid this iron tie rods were used about 12 feet long, $\frac{1}{4}''$ iron 4″ wide with round bolts through one ene $2\frac{1}{2}''$ long each side, with other ends squared off with iron of same width. There were five of these on each face, holes being drilled for the bolt end in stones 3 and 4, 5 and 6, 7 and 8, etc., and the other end being built up back in the brick work. Coursing and heading spirals were marked over the lagging so that masons could have a line to which to lay brick, the coursing spirals were marked every six courses of brick. The heading spirals are not important in brick work as they could hardly be followed with the eye after centres are removed. Points on a coursing spiral are obtained thus: see Plate No. 4, the angle $E' C C' = 23° 52'$ by a calculation from triangle $C c E'$; divide $c E'$ into same number of equal parts as the semi-circle on $A B$, then $C q =$ three of the equal parts of $C E'$ and $q 7'''' = q l - l 7''''$; $q l = C q \sin 23° 52'$, and $l 7'''' = \text{vers sin } B O 7$; then setting the transit on top of lagging on the centre line of arch turn the angle 23° 52′, lay off the distances $c q$ and $q 7''''$, three or four such points will determine the spiral. Next take a straight edge 18′ long, $\frac{1}{2}''$ thick and 8″ wide, lay over these points and mark the spirals. The length of the springing line being 80′ 2″, ring stone 40, or the oblique

quoin stone takes up 2′ 4⅞″ of this length, found by multiplying 1′ 8″ (the chord of a right section equivalent to the thickness of a ring stone, see Plate No. 6, Fig. 3,) by *cot* β. The length of the quoin stone 1 is 4′ 5″, this gives a length along the winding bed or coursing joint of 3′ 7½″, making the length of the skew back along the coursing joint conform with the lengths of the ring stones; of the length on the springing line we have left 73′ 4⅛″, this is divided into 183 checks of $4\frac{13}{16}$″ each, see Plate No. 5, Fig. 2. These checks measure $3\frac{15}{16}$″ along a coursing spiral, 2¾″ (thickness of one course of brick) along the heading spiral, and are 30″ deep from intrados to extrados, the arch being turned with seven courses of brick. The checks were made of the same dimensions at the extrados as at the intrados, in an arch all stone the top of the check would have to be a little higher at the extrados, but it is unimportant in a brick arch. In setting the ring stones a template, see Plate No. 7, Fig. 6, was used to tell if the ring stones were high or low behind, this result could also be obtained on the face by stretching a string from the centre of eccentricity along the face joint. In the template, *B C D* is cut with a radius of 14′, and the edge *A B* is on the radius produced. The straight arm was applied to the bed of the stone and at right angles to the axis of the arch, the curved portion laying over the lagging and being plumb.

The centres were placed generally 3′ 9″ apart in the clear, the lagging was 3″ thick; full centres extended to the centre of the face at each end, and half centres were used to complete the acute corners. Where the bents of the alternate trestle were, the centres had to be spaced as the piling would allow. There were 10 plumb or bater posts which went up through the centres besides numerous braces. The arch was turned over the south end, or where the main trestle was first; this portion was then filled over and the C. W. & B. traffic thrown back from the alternate to the main track; the alternate trestle was then torn out and the remaining portion of the arch completed. There were four varieties of stone used in the work; the impost being made of a very hard blue limestone from Greensburgh, Indiana; the quoin and ring stones of an Oolitic limestone from near Indianapolis; the south face and the wings of a soft sandstone from Lancaster, Ohio, this sandstone hardens with exposure and age; the rest of the arch was built of a freestone from Portsmouth, Ohio, not as good a wearing stone as any of the above. Machine made stock brick

were used on the inside course. There were about 164,000 bricks used in the whole arch. The cement used was mostly "Louisville," of the "Horse Shoe" and "Black Diamond" brands, some "Cummins Akron" was also used; in the whole arch about 2,400 barrels. No grouting was done, except in case of ring stones, and face joints; the backing and foundation was made up of concrete. There was a line of 12″ drain pipe laid on each side from face to face of the arch through the backing to act as conduits in which to carry the telegraph wires.

The following is a statement of the cost of the arch, together with that of the other work in connection with it, and consequent to the crossing of the two railroads, by taking items 1, 2, 3, 4, 7 and 12 we obtain the cost of the arch proper, or without the expense arising from the crossing of the other railroad, to be $46,350.13.

QUANTITIES.		MATERIALS USED OR HANDLED.	PRICE.	COST.
1	3593	Yards first-class arch masonry	$10 00	$35,930 00
2	13034	Lin. feet piling in foundations	38	4,952 92
3	23621	Feet B. M. timher	22 00	519 66
4	2254	Pounds iron	02½	56 35
5	4283	Yards earth excavation	23	985 09
6	6915	Yards loose rock excavation	38	2,627 70
7	3398	Yards wet excavation	90	3,058 20
8	135780	Feet B. M. timber in trestles, etc	19 00	2,579 82
9	1206	Hours labor on trestles, etc	2 50	3,015 00
10		Engine hire (C., W. & B. helper)		4,138 07
11		Cost of siding and C., W. & B. track gang work		1,143 30
12		Extra cost of stone and stone cutting		1,833 00
				$60,839 11

There was no distinction made in the classification of the masonry, foundation, backing and brick work being all called first-class. As noted, the second item is for piling in foundation, the piling used in the trestles appearing in the item "timber in trestles, etc." Timber in foundation refers to 10″ × 12″ caps and 4″ plank covering them only. The iron in foundations is the weight of drift bolts and spikes used in spiking down the caps and planking. The earth, loose rock and wet excavation includes cutting through the C., W. & B. embankment, sinking the foundation pits and borrowed material to make the C., W. & B. bank after arch was finished. The item "timber in trestles, etc.," also includes the piles in the same and sheeting plank and bracing for the foundation pits.

The "labor on trestles, etc." includes framing and erecting trestles, driving piles for the same, maintaining and altering them during the progress of construction, and tearing them out when the arch was finished, also labor in sheeting and bracing founda-

tions. In explanation of the item "engine hire," it must be recalled that the point of crossing of the two railroads was at a marked depression in grades on the C., W. & B., so that in case of heavy freight trains it was necessary to have an extra engine to help such trains up the heavy grades. All trains slowed up going over trestles, nominally to 8 or 10 miles an hour, though some ran at least 25 miles an hour. In all an average of 52 trains per day crossed the trestle. The helper being an additional expense to the C., W. & B., our company had to meet it. A siding was put in for our use in connection with the building of the arch, and their track gang had several days work in the line of shifting their tracks and the constant expense of a watchman.

The Oolitic stone cost considerable more than the other varieties of stone used, and the stone cutting on the impost, quoin and ring stones was undoubtedly in excess of what is ordinarily considered first-class masonry. The engineer of construction very properly made a suitable allowance to the contractor for such extra work. The centres were also extra heavy to help carry track, if necessary, and some allowance was made the contractor for this also.

J. Foster Crowell, M. Am. Soc. C. E., was engineer of construction from whose plans entirely the arch was built. I was indebted to him for many practical suggestions and solutions of knotty points which presented themselves during the construction. Mr. S. Casparis was the contractor and Thomas Owens the foreman mason. The shifting stock was the idea of my rodman, E. T. McConnell, and to his interested application and close inspection of the work is due much towards its successful completion. Mr. McConnell also assisted me in preparing the drawings and ring stone models for this paper.

EASEMENT CURVES.

An easement curve is one in which the transition from the tangent to the curve, or the reverse, is gradual. That is the curve begins with a radius of infinity and is gradually reduced till it has the radius of the circular curve.

The curve that theoretically fulfils all the necessary conditions is the cubical parabola. In going around a curve, a certain amount of centrifugal force is generated by the train, and in order to make the resultant of the centrifugal force and the weight of the train be perpendicular to the plane of the rails, the outer rail

is elevated an amount $h = \frac{g\,v^2}{32\frac{1}{6}\,R}$ where $g =$ gauge of track, $v =$ velocity in feet per second and R radius of curve.

Now, in the transition from the tangent to the curve, this elevation h is not made all at once, but is gradual.

Suppose that the rate of rise is uniform and is represented by $\frac{1}{i}$. Let A be the $P.\ T.$, and let x, y be the co-ordinates of the curve, x measured along the tangent AI.

Then $\frac{1}{i} =$ rise of outer rail at 1 foot distance from A.

$\frac{x}{i} =$ rise of outer rail at x feet distance from A.

$r =$ radius of curve at point x.

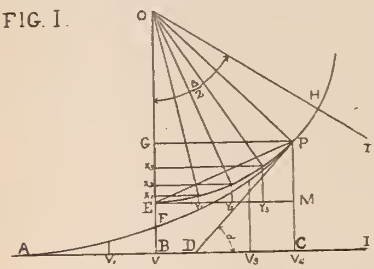
$$\frac{x}{i} = \frac{gv^2}{32\frac{1}{6}\,r},\quad r = \frac{gv^2 i}{32\frac{1}{6}x};\quad \frac{gv^2 i}{32\frac{1}{6}} = \text{a constant} = P.$$

Then $r = \frac{P}{x}$. Now $r = \dfrac{\left(1 + \frac{dy^2}{dx^2}\right)^{\frac{3}{2}}}{\frac{d^2y}{dx^2}} = \frac{ds^3}{dx\,d^2y} = \frac{dx^3}{dx\,d^2y}$ approx. $= \frac{dx^2}{d^2y}$

Therefore $\frac{d^2y}{dx^2} = \frac{x}{P},\ \frac{dy}{dx} = \frac{x^2}{2P},\ y = \frac{x^3}{6P} =$ equation of cubical parabola.

The value of P must be determined for any case, and it depends on the value of v and i.

FIG. I.



When R is large, v would be greater than if R were small, and i would also be less in the first case, so P would be greater, the greater the value of R. According to Rankine, $i =$ about 300 and $P = \frac{300\ gv^2}{32\frac{1}{6}}$, $g = 4'\ 8\frac{1}{2}''$, $v =$ about 25 miles per hour. This gives $P =$ about 60,000.

Let P be the point where the radius of the parabola becomes equal to the radius of the circle, and let its co-ordinates be a and b.

Then $AC = a$, $PC = b$, $R = \frac{P}{a}$, $\therefore a = \frac{P}{R}$.

Draw PD tangent to both curves at P.

Tan. $\alpha = \frac{dy}{dx} = \frac{a^2}{2P}$. From equation of cubical parabola, $b = \frac{a^3}{6P}$

or $P = \frac{a^3}{6b}$ $\quad\therefore$ tan. $\alpha = \dfrac{a^2}{\frac{a^3}{3b}} = \frac{b}{\frac{1}{3}a} = \frac{b}{DC}$. $\therefore DC = \frac{1}{3}a$ and

$AD = \frac{2}{3}a$.

Produce the circular curve to E, where its tangent becomes parallel to AI. $POG = PDC = \alpha$. Tan. $\alpha = \frac{PG}{OG}$

$\therefore\ PG = BC = OG$ tan. $\alpha = (R - EG)$ tan. $\alpha = R$ tan. α (nearly), since EG is very small compared with R; but $R = \frac{P}{a}$,

tan. $\alpha = \frac{a^2}{2P}$ and $BC = \frac{P}{a} \times \frac{a^2}{2P} = \frac{a}{2}$; $\therefore AB = \frac{a}{2}$.

From equation of curve, since $AB = \frac{a}{2}$, $FB = \frac{b}{8}$.

Now $BE = BG - GE = b - GE$, $GE = \frac{2PG^2}{8R}$ nearly (Searle's Engineering, Art. 199.)

$GE = \frac{a^2}{8R} = \frac{a^3}{8P} = \frac{3}{4}b$, since $b = \frac{a^3}{6P}$. $\therefore BE = \frac{1}{4}b$, and the curve at F bisects the line BE.

For laying out the curve, we have given the intersection angle $\triangle$, and radius R, to find $AI = T$.

Having determined P, $a = \frac{P}{R}$, and $b = \frac{a^3}{6P}$ and $T = \frac{1}{2}a +$ $(R \times \frac{1}{4}b)$ tan. $\frac{1}{2}\triangle$.

Hence we can measure off T from I and get A. We can then lay out the curve by ordinates x, and y. To get on the tangent at P, we lay off from C, $CD = \frac{a}{3}$ and PD is the tangent.

If we assume T, we can solve above equation for R. Another method of applying the cubical parabola is to assume the length of transition curve needed, taking as your guides the topography of the country, the degree of circular curve, etc.

Then determine the lengths of the ordinates and abscissas for a circular arc for a chord PE half the length of that of the transition curve.

To do this, $\sin PEM = \frac{LE}{OE}$ and $MP = PE \sin PEM$.

$$\text{Also, } EM = PO \sin POE,$$
$$Ey_1 = PO \sin p_1 OE,$$
$$Ey_2 = PO \sin p_2 OE,$$
$$Ey_3 = PO \sin p_3 OE, \text{ etc.}$$

Then for this cubical parabola,

$$A\,V_4 = 2\,E\,M,$$
$$A\,V_1 = 2\,E\,y_1,$$
$$A\,V_2 = 2\,E\,y_2,$$
$$A\,V_3 = 2\,E\,y_3.$$
$$\text{Also, } V_4\,P = \tfrac{4}{3}\,M\,P.$$

Any other ordinate may be found by dividing the value of $V_4 P$, by the cube of the number of stations, and multiplying this quantity by the cube of the number of the stations commencing at A.

Thus for p_3, $v_3 p_3 = \dfrac{V_4 P}{(4)^3} \times (3)^3$.

The reasons for these steps can readily be seen from the above properties of the cubical parabola. Having arrived at P, we can run in the circular curve by offsets from the tangent, or by deflection.

Another form of easement curve, and one that can be located by deflection in the same manner as a circular curve, is a spiral proposed by Mr. Ellis Holbrook, C. E. It is a curve whose radius begins at infinity, and varies inversely with the length. Then let R = radius of curvature at any point.

l = length of curve from tangent point.

A = some constant.

Then the definition of the curve is $R\,l = A$.

Take a spiral whose degree of curvature increases 1 minute for every foot of increase of length.

Now $\dfrac{180 \times 60}{3.1416}$ = number of minutes for an arc equal in length to the radius = 3437.75 minutes.

Then if l = 3437.75 ft. the degree of curve = 3437.75 minutes and it is the angle at the centre subtended by an arc of 100 feet.

Hence for l=3437.75 ft., R=length of arc comprised in degree of curvature = 100 ft., and $A = Rl$ = 3437.75 is the value of the constant A.

Then $R = \dfrac{3437.75}{l}$, and we can compute values of R for different values of l, say 10 ft. apart, and from 0 up to about 300 ft.; which would be about as long a transition curve as would ever be used.

Also, let i = the inclination of the curve in minutes to the tangent at any point.

Then $di = \dfrac{l}{100}\,dl$, or $i = \dfrac{l^2}{100}$.

From this equation we can compute values of i for the same values of l as before.

If we express this value of i in terms of radius as unity $i = \frac{l^2}{3437.75 l^2} = .0000014545\, l^2 = al^2.$

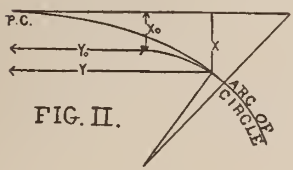


FIG. II.

Refer the curve to rectangular axes, with the origin at $P.\ C$, and the tangent as the axis of y.

For purposes of laying out the curve, it will be convenient to have x and y in terms of l.

$$Cos\ i = \frac{dy}{dl}, \quad \therefore dy = cos\, i\, dl = cos\, a\, l^2 dl,$$

$$y = \int_o^l cos\, a\, l^2 dl.$$

Develop $cos\ a\, l^2$ by Maclaurin's formula:

$$Cos\, a\, l^2 = 1 - 12 \frac{a^2\, l^4}{\lfloor 4} \times \frac{d\, a^4\, l^8}{\lfloor 8} \text{—etc.}$$

Hence $y = l - \frac{12\, a^2\, l^5}{\lfloor 5} + \text{etc.}$

Substitute value of a given above, $y = l - .00000000000211551\, l^5$.

Also, $dx = sin\ i\ dl = sin\ a\, l^2\ dl.$

$$sin\ a\, l^2 = -\frac{2\, a\, l^2}{\lfloor 2} + \frac{b\, a^3\, l^6}{\lfloor 6} \text{ etc.}$$

$$x = -\frac{2\, a\, l^3}{\lfloor 3} + \text{etc.} = .0000004848\, l^3 + \text{etc.}$$

From these equations, we can compute values of x and y corresponding to the different values of l. If x_o and y_o are the coordinates of the points where the circle joining the spiral at the point x, y, if produced becomes parallel to the tangents, then $x_o = x - R\ vers\ i$, and $y_o = y - R\ sin\ i$. From these, values of x_o and y_o are computed. If d be the deflection necessary to be turned off from point y_1, on tangent to point x, y on curve, then $tan\ d = \frac{x}{y - y_1}$. If y_1 be $P\ C$, then $tan\ d = \frac{x}{y}$. From these we can complete values for d and for d_1, taking for d_1, $y_1 = 200$ feet.

We can also add a column giving the length of chord for arc of 50′ for the different degrees of curvature. After we have made these calculations, we have all that is necessary to lay out an easement curve corresponding to any circular curve.

For let I equal the intersection angle, T equal the length of the tangent, then from the from the figure, it can easily be seen that $T = R\ tan\ \frac{1}{2}\ I + x_o\ tan\ \frac{1}{2}\ I + y_o$.

We have given R, and we can thus see from our table what values of x_0 and y_0 correspond to it.

Having found T, we can lay it off from the vertex and get $P. C.$ We can then set up at $P. C.$, and locate different points on the curve by deflections, using the values in column headed d Or if on account of any obstacle, deflections can not be used, we can use the values of x and y, and locate the curve by ordinates.

Having arrived at the point where the spiral joins the circle, to get on a tangent to the circle, set up at this point and sight on $P.C.$ or y_1, and turn off $i-d$, or $i-d_1$.

It will be seen that all curves will begin and end alike, and for different values of I and R, we use different portions of the same curve.

These are a few of the numerous forms of transition curves used. They serve to give an idea of the different methods employed.

Every railroad of any consequence has its own special rules and methods, and although they all seem to be very different, yet they all give essentially the same curve. They are not employed until the final line is run, preparatory to laying the rails, which must then be bent to suit the required amount of curvature.

S. W. FRESCOLN.

THE MOVEMENT OF THE CONESTOGA RAILROAD BRIDGE.

The writer having the good fortune to be present at the moving of one of the large bridges by the Pennsylvania Railroad Company, (several of which were moved during the past year) wishes to submit in a brief manner a few points of possible interest to the Society. These bridges were moved to new positions to act as temporary crossings during the construction of permanent stone-arched structures in the old positions. The bridge in question was the one across the Big Conestoga Creek, about one mile east of Lancaster, Pa., and was moved on a Sunday in August, 1887. It consisted of three spans, the one at the western end being a plate girder 40 feet long and about 4 feet deep. The other two spans were of equal length and consisted of double system Pratt trusses about 18 feet deep. The bridge was a double-track deck bridge, having a total length of 340 feet and a weight of about 425 tons; its lower chords were 58 feet above the water. Previous to the moving, a

section of track had been laid, branching off from the main track on each side of the creek, the bridge forming the connection between these sections. Three hundred thousand feet of timber were used in making the trestle work which formed a support for the bridge as strong as the old one. Considering the weight of the structure, the work of raising it in order to place the rollers under it was no small item. One 90-ton, three 60-ton, and two 30-ton air jacks were used (one of the 60-ton jacks collapsed during the operation). It was raised about 15 inches, or sufficiently to admit two railroad rails with a three-inch roller between them. The track on either side was graded as the bridge was raised, so as not to delay travel. First, three railroad rails placed side by side head upwards in the usual manner were put down; upon these, and at intervals of about eighteen inches, rollers, three inches in diameter and two feet long, made of solid bars of iron, were placed; next, upon these and vertically above the other rails, were placed three rails with their bases against the bottom of the bridge, or in the reverse position, so that the rollers were between the heads of the rails. One of these tracks was placed at each end of the Pratt truss, two in the middle of it, and under each end of the plate girder were placed two rails with rollers between, arranged as in the other cases. Tramways or tracks were built from each of these upon trestle work connecting the old with the proposed new position, and continued over the new position. At the end of each tramway was placed a crab, or small windlass, which was rigged with new one-inch ropes; to look at these ropes, which were to pull so large a structure, the uninitiated would have supposed them to be wholly unable to withstand the apparent strain; but scarcely had they been made taut before the bridge began to move. Four men operated each of the four larger crabs and two each of the two smaller ones; making a total of twenty men who pulled the immense mass of iron. It was moved a distance of 44 feet, 8 inches, and it required fifteen minutes in which to do it. Several men were stationed on the bridge, who kept the rollers and rails constantly oiled. The moving was accomplished without a jar, and scarcely an order from the officials. Hardly a sound was heard except the voices of the markers at each crab registering the progress of the bridge at their respective points. The accomplishment of the feat was greeted with loud cheers by the crowd, which numbered over five thousand people. The tracks on the bridge were then connected with those of the section

at each end, a slight delay being caused by the connecting rails not being of the correct length; but in one hour and twenty minutes from the time that the mail train west passed over the bridge, it was ready for service in the new position. The rollers were left in the positions which they occupied when the moving ceased, in which positions they will remain until the bridge is taken down.

CHAS: H. MILLER.

ALUMNI NOTES.

1875.

—W. A. Lathrop, C. E., is to be congratulated upon his advancement to the position of General Superintendent of the Lehigh Valley Coal Company, succeeding the late Frederick Mercur. His office is located at Wilkesbarre, Pa. For about six months after his graduation, Mr. Lathrop was engaged in mine surveying with Mr. J. A. Stearns of Wilkesbarre, and then entered the service of the Lehigh Valley Railroad Company as Assistant Engineer, the office at that time being at Bethlehem. He retained this position until about 1880, when he again returned to his former work with Mr. Stearns. During 1881, he went to Midvale, N.J., as Superintendent of the Midvale Ore Company, and in the following year removed to Tazwell County, Va., where he remained for about three years as Superintendent and Engineer of the Coal and Coke Department of the Southwest Virginia Improvement Company. Since that time, he has been engaged as Superintendent of the Snow Shoe Division of the Lehigh Valley Coal Company, with headquarters at Snow Shoe, Pa. From 1879 to 1881, he was an Honorary Alumni Trustee of the University.

1883.

—F. W. Dalrymple, C. E., who for a number of years has been Division Engineer on the Delaware Division of the New York, Lake Erie & Western Railroad at Port Jervis, N. Y., has been promoted to the position of Roadmaster. His address is Bradford, Pa.

1884.

—L. B. Semple, B. A., has been appointed Instructor in Latin and Greek in the Lehigh University.

1885.

—F. B. Petersen, C. E., Instructor in Metallurgy and Mineralogy, has resigned his position and gone to Arizona for the benefit of his health.

—J. H. Wells, C. E., is connected with the Department of Public Works, Water Purveyor's office, room No. 1, 31 Chambers Street, New York.

1886.

—W. A. Lydon, E. M., has recently been elected a Junior Member of the American Society of Civil Engineers.

—L. J. H. Grossart, C. E., has been engaged for some time in making a survey for the Lehigh Valley Railroad beyond Elmira.

—S. C. Hazleton, E. M., has been appointed Instructor in Metallurgy and Mineralogy, to take the place made vacant by the resignation of Mr. Petersen.

1887.

—J. B. F. Hittell, C. E., is on the Engineer Corps of the Illinois Central Railroad at Jackson, Tenn.

—C. F. Zimmele, B. Ph., is at present engaged in teaching in the Moravian Parochial School of Bethlehem.

—G. T. Richards, C. E., is with Wainwright & Wilkins, Engineers and Contractors, Fourth Avenue, Pittsburgh, Pa.

—The annual meeting of the American Society of Civil Engineers was held in New York on Jan. 18. The following officers were elected for the current year: President, Thomas C. Keefer of Ottawa, Canada; Vice Presidents. J. J. R. Croes of New York and Robert Moore of St. Louis; Secretary and Librarian, John Bogart of New York; Treasurer, George S. Greene, Jr., of New York; Directors, Mendes Cohen of Baltimore, Joseph M. Wilson of Philadelphia, Stevenson Towle of New York, Charles B. Brush of Hoboken, and Alphonse Fteley of New York.